Mechanical Engineering Design Portfolio

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Harmonic Bionics

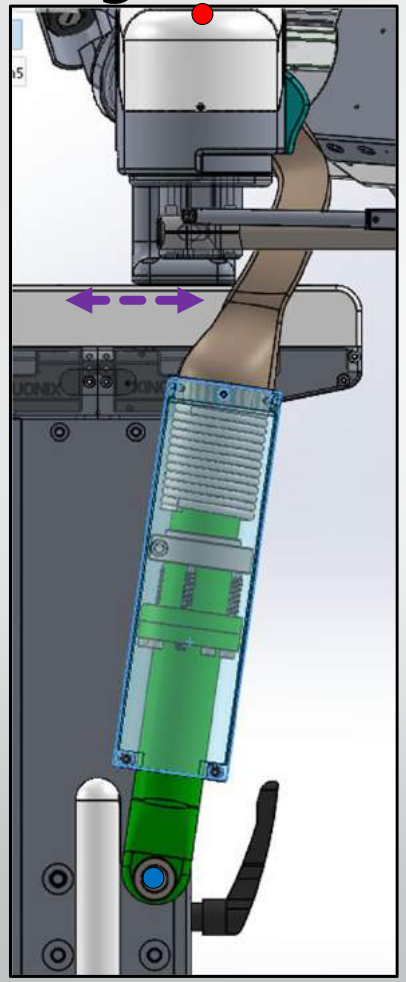
Spring Counterbalance Mechanism

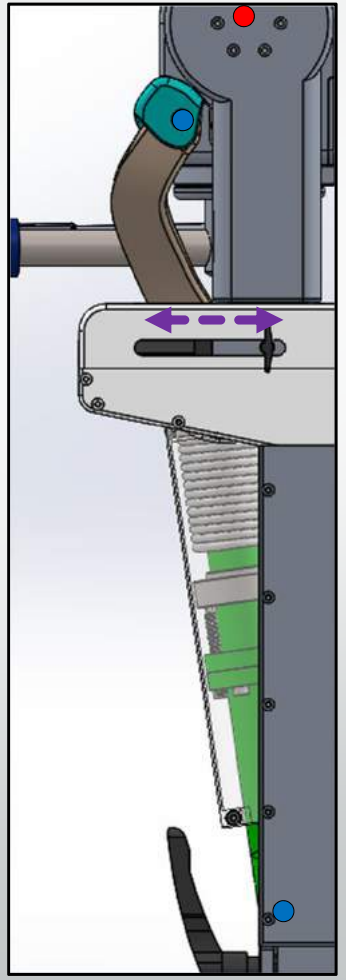
Problem: 30.8 Nm actuator only ever exerts torque to lift the robotic exoskeleton arm (thus only using half of its available torque range). Also, if the robot unexpectedly shuts down, entire weight of arm will fall upon the patient.

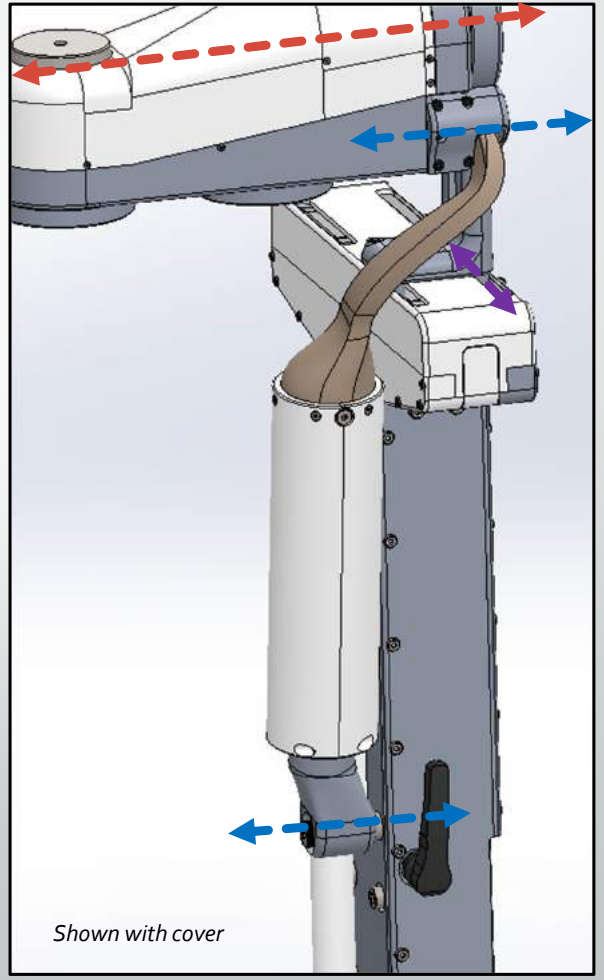
Task: Design a counterbalance mechanism that will provide near-constant upward torque. Must be retrofitted to existing assembly, which includes a mechanism for adjusting the position of the actuator.

Legend:

- Actuator Axis
- Counterbalance Axes
- Actuator position adjustment linear axis
- Spring counterbalance assembly







Shown with cover

Spring Counterbalance Mechanism

Spherical bearing joint (to prevent over constraint)

Shoulder screw for secondary retention of alignment shaft (to prevent catastrophic failure)

Integrated, flexured shaft clamp

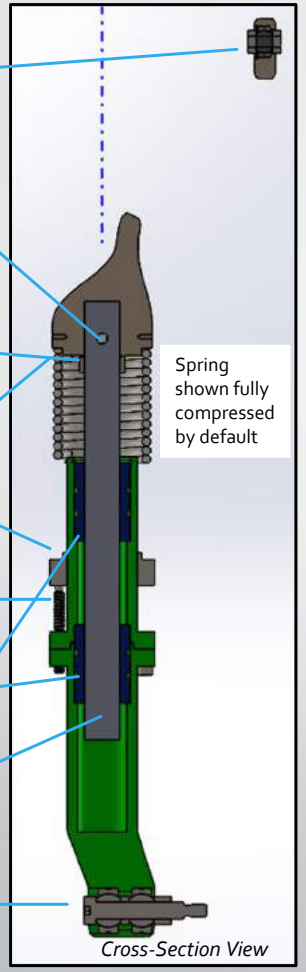
Spring seats

Custom shaft collar and jack screw mechanism to adjust spring preload

Double linear bearings for moment resisting capabilities

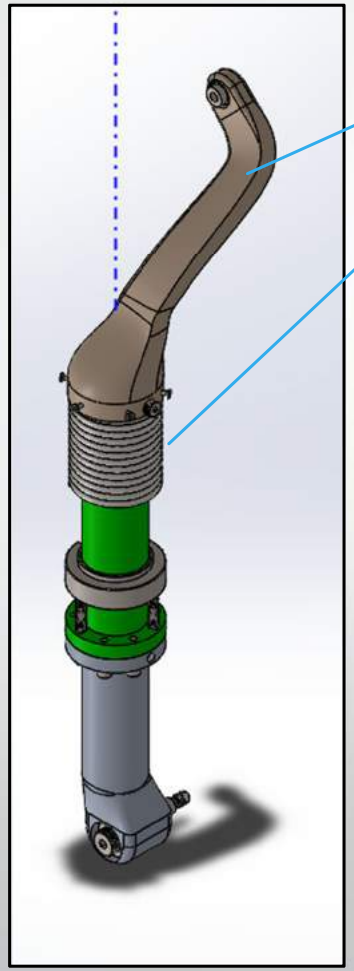
Alignment Shaft

Pin joint with shoulder screw



Spring shown fully compressed by default

Cross-Section View

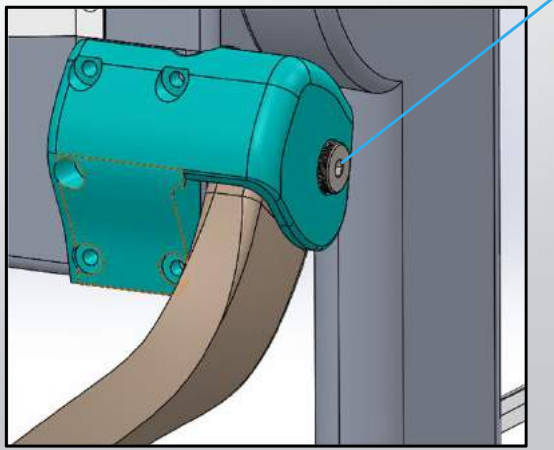


Complex swept geometry needed to fit around existing assembly

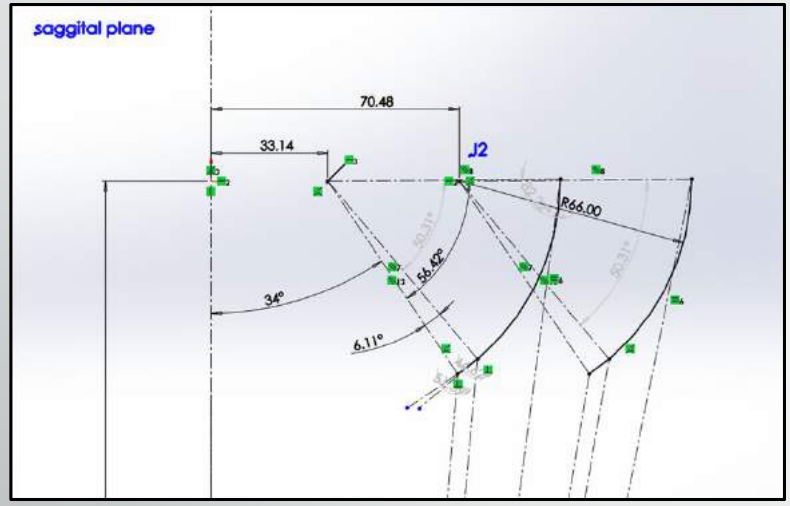
176 lbf, 32.2 lbf/in compression spring

The mount (shown in cyan below) covers the joint for aesthetics and to protect users and hardware in the case of shoulder screw failure.

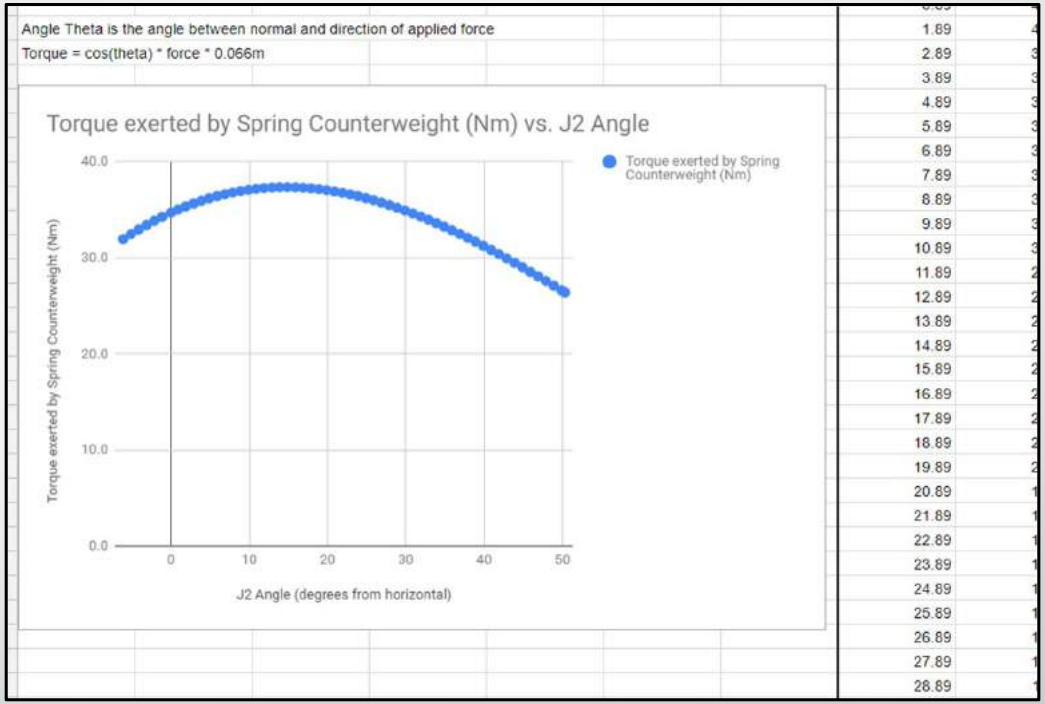
Shoulder screw



Calculations



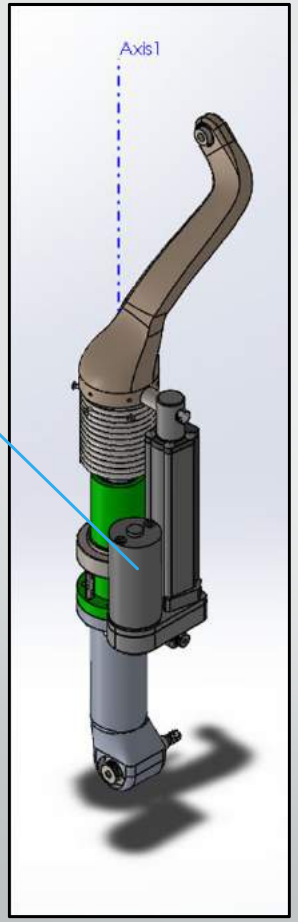
SolidWorks sketch of actuator axis position range and actuator angular position range, used for initial design and spring selection.

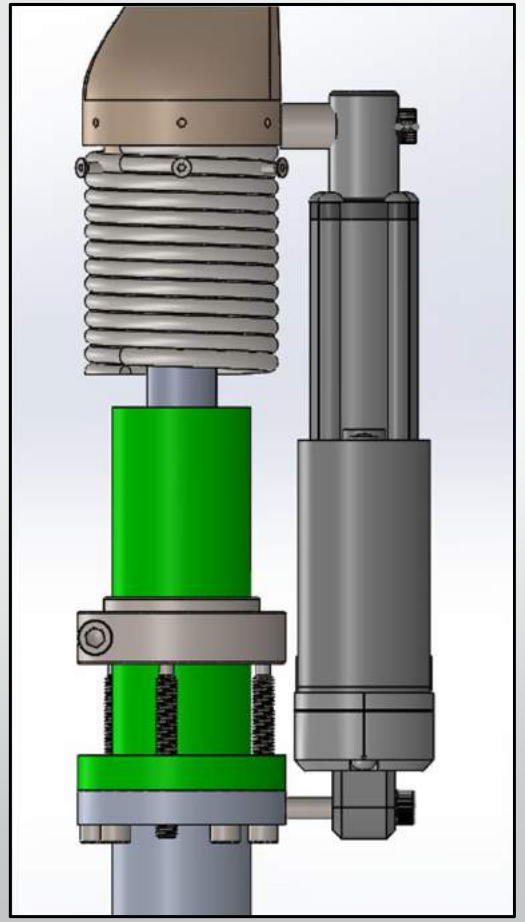


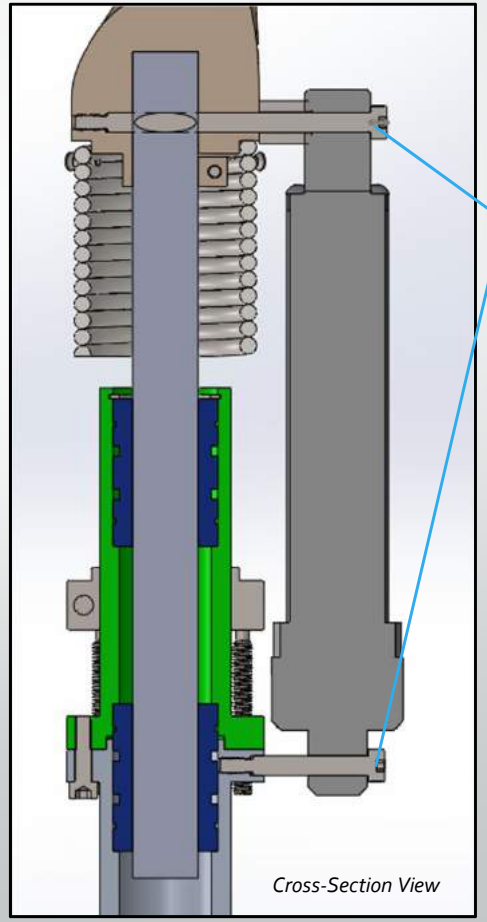
Afterwards, I solved for all geometry analytically and calculated torque vs actuator angle for any given spring constant, preload, and actuator axis position. I generated the graph shown above with Excel. The goal was to approximate a constant-torque spring.

Assembly Tool

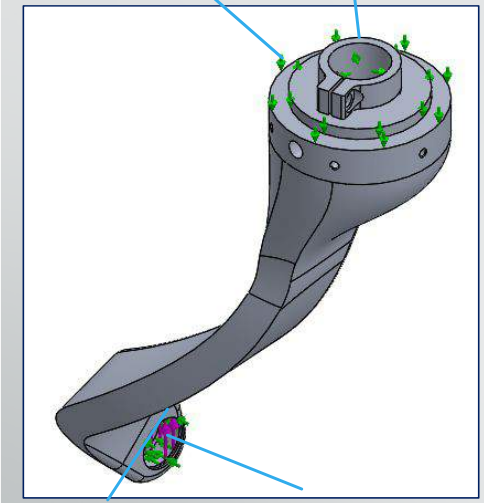
I created an assembly tool with a linear actuator to safely compress and retain the spring as the mechanism is being installed on the exoskeleton.





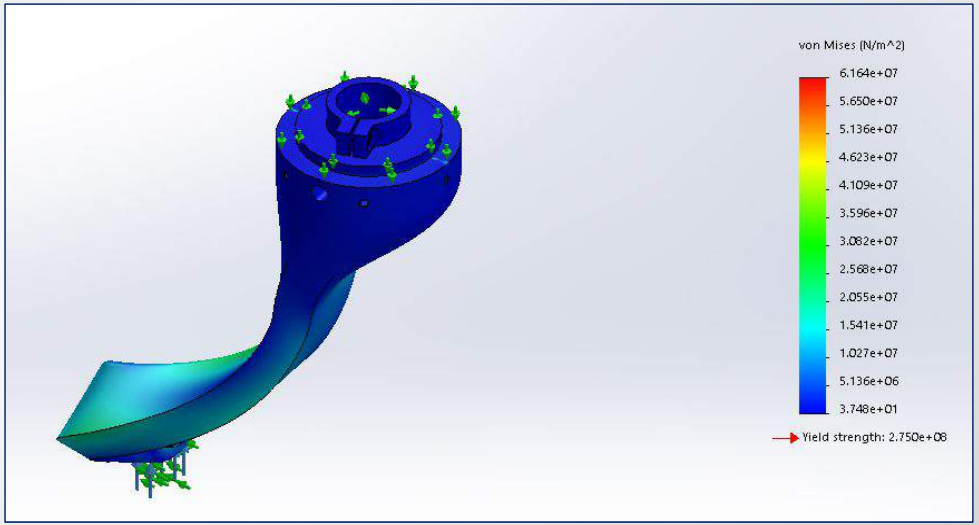


FEA





Final Meshing; all features resolved



FEA assumptions:

1) Spring is uniformly bonded to spring seat
2) Shaft is uniformly bonded to ID
3) Excludes any misalignment of the mechanism

Results from this study and others give a high safety factor of about 3.5. A high safety factor is desired for the following reasons:

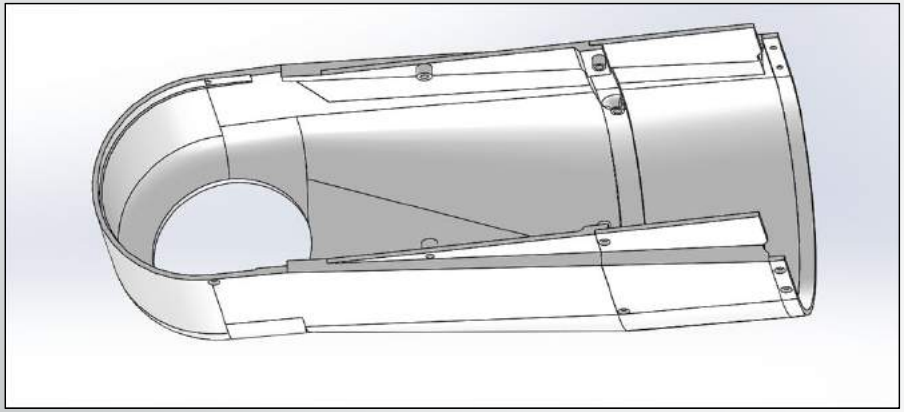
1) The part will be subject to many cycles of rapid loading. Such a high safety factor (along with other analysis) reduces concerns of fatigue failure.
2) Failure of this part will likely be catastrophic; the material will yield in a way that increases the leverage of forces on the part, and ultimate failure will result in the rapid release of spring energy.
3) This part is not being supported by any actuators or the patient; thus, weight is not a major concern.

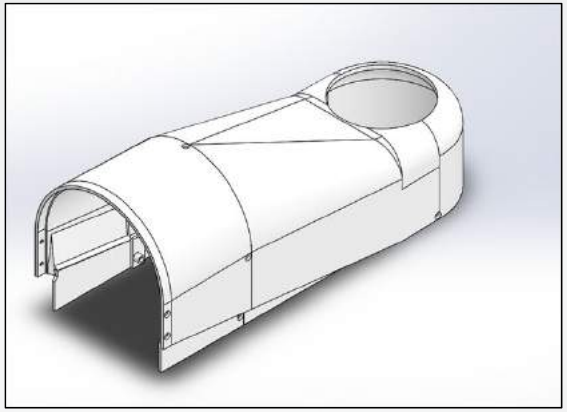
Assembled Mechanism





More Design Work



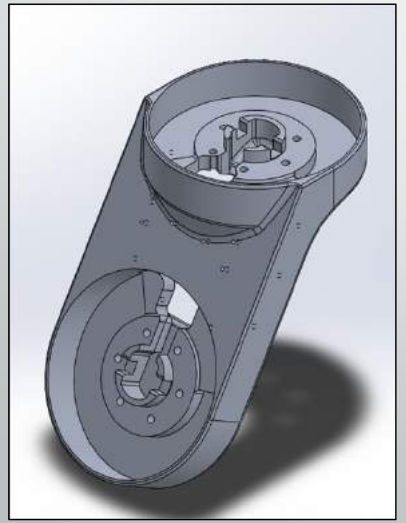


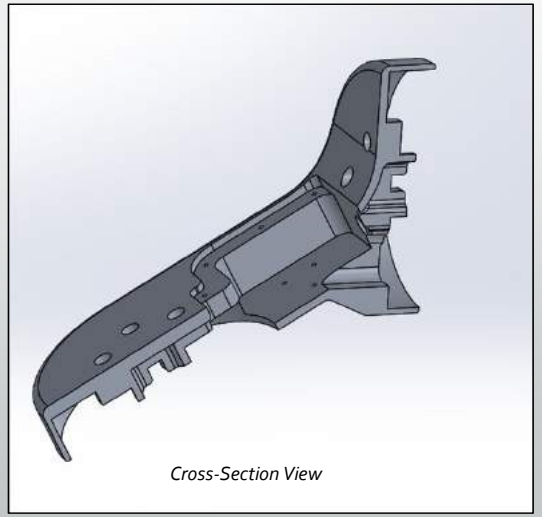
Additively Manufactured Actuator Housing Cover

- Redesigned from scratch
- Two separate bodies that both fit within Ultimate 3 build plate
- Holes for threaded inserts
- Mating flanges that match contours of housing

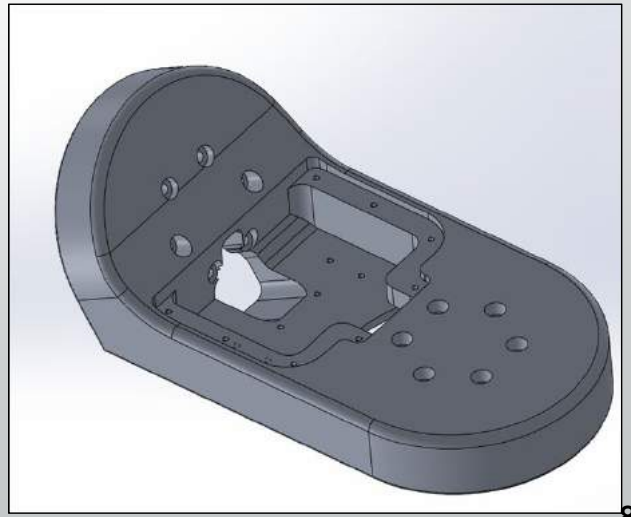
Joint 5 Output Link

- Extensively modified
- Added large access hole for a wiring disconnect point
- Ran FEA analysis and made appropriate changes





Cross-Section View



Harmonic Bionics

"Jeremiah is extremely thorough in every task that he does. If there are unclear aspects in the problem statement given to him, he puts in the extra effort to study the system and create well informed designs. …

… He actively seeks out opportunities to learn and expand his knowledge base. Jeremiah is willing to go through difficulty on a new task or method in order to learn new tools and features that will be useful to him or to the team down the line. "

- **Rohit Varghese, Direct supervisor at Harmonic Bionics, Head of Product Design**

Full recommendation: https://www.linkedin.com/in/jeremiah-coholich/

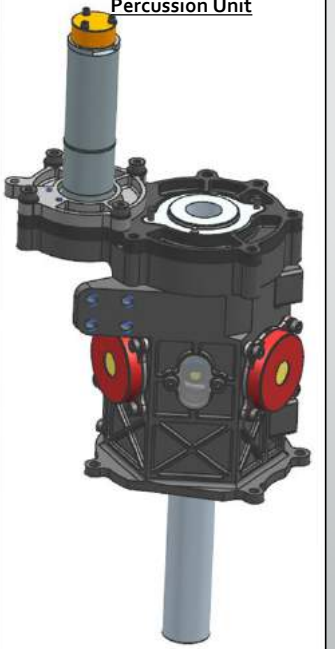
Reference contact info available upon request.

Spring Testing and Characterization

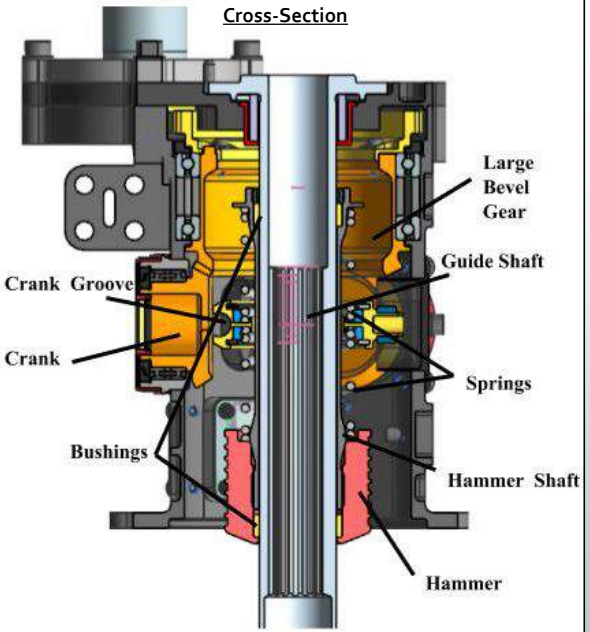
Problem: Spring performance is critical to functioning of the percussion unit (spring-mass system) used in the Mars 2020 Rover coring drill.

Task: Design a test setup to obtain reliable force-displacement data for hammer mechanism without disassembly and removal of individual springs. Analyze and report resulting data. Must use IMADA FSA-1KE Material Tester without changing configuration.

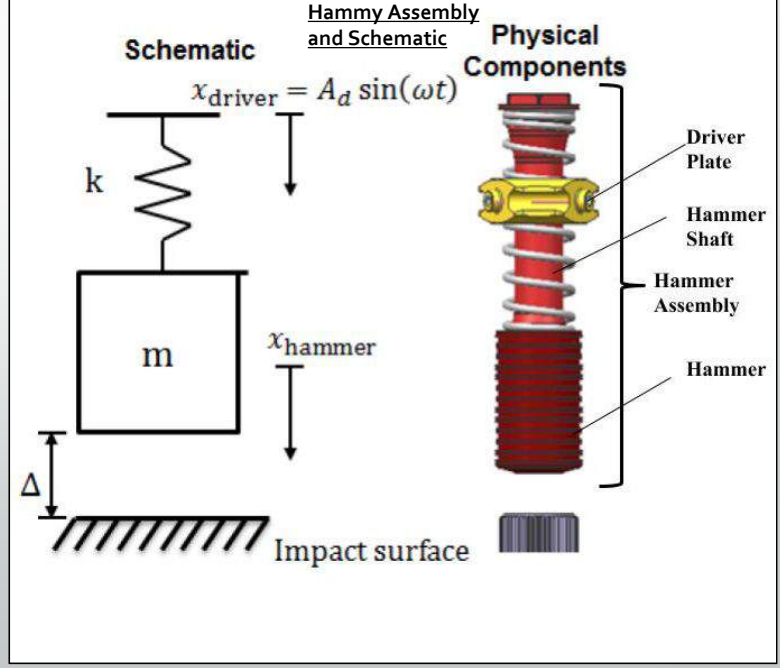
Percussion Unit



Percussion Unit
Cross-Section

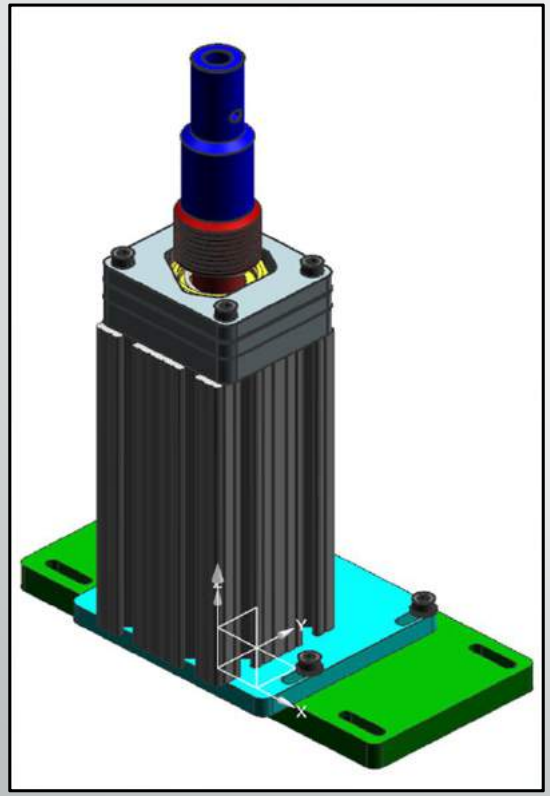


Hammy Assembly
and Schematic

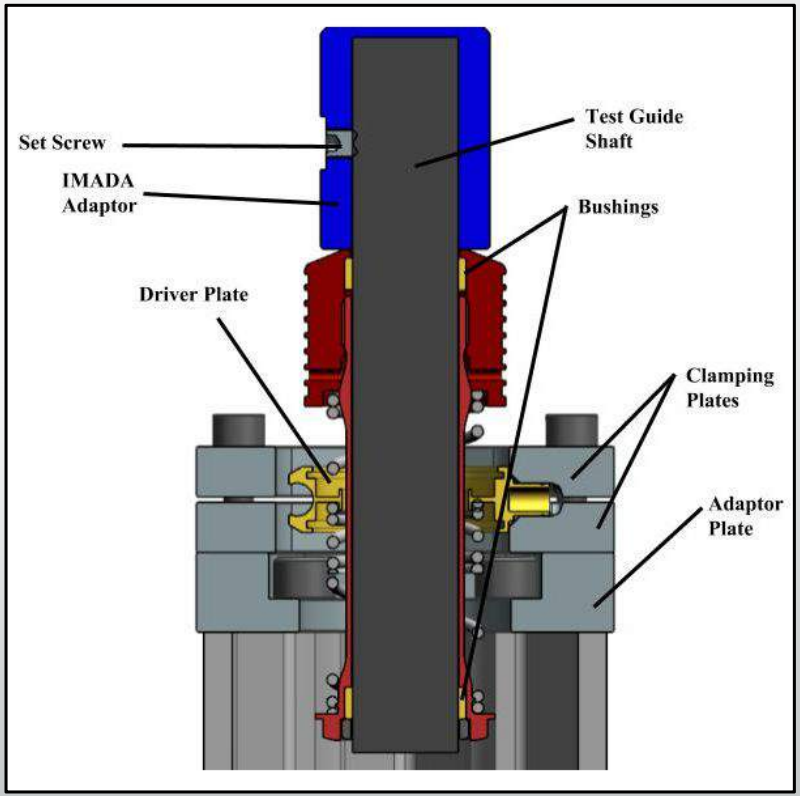


Hammer Assembly Spring Tester Design

My design consists of a stand with slots to adjust the x and y position to ensure axial alignment. A shaft, attached to the IMADA force probe, centers and stabilizes the hammer mechanism. The plates on the top clamp down on the hammer assembly's driver plate.

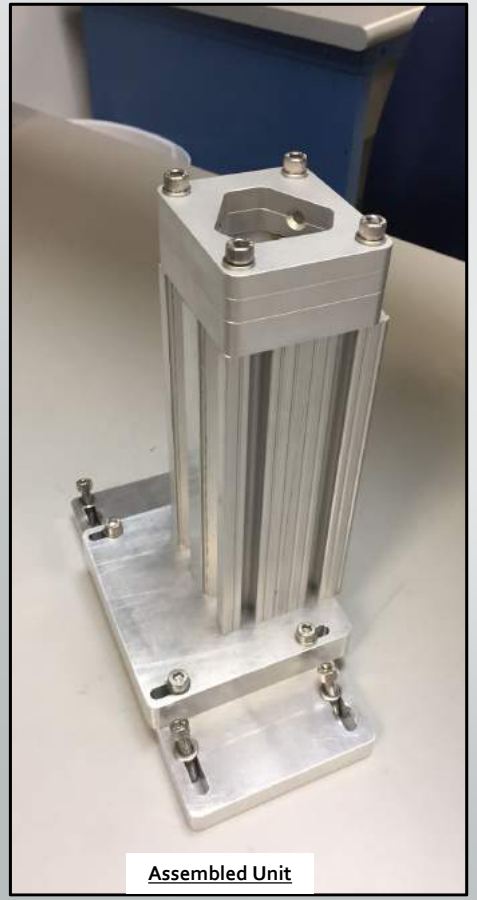


Design Isometric View

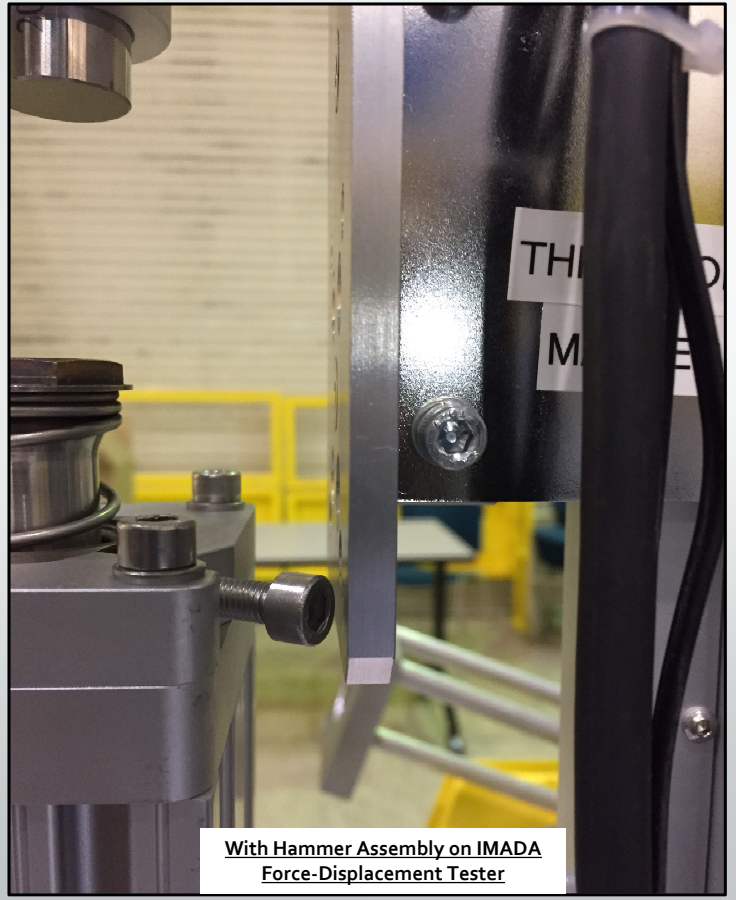


Cross-Section View with Hammer Assembly

Assembly and Testing



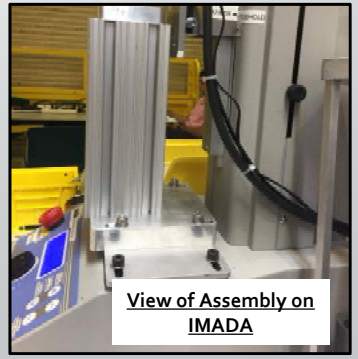
Assembled Unit



With Hammer Assembly on IMADA Force-Displacement Tester



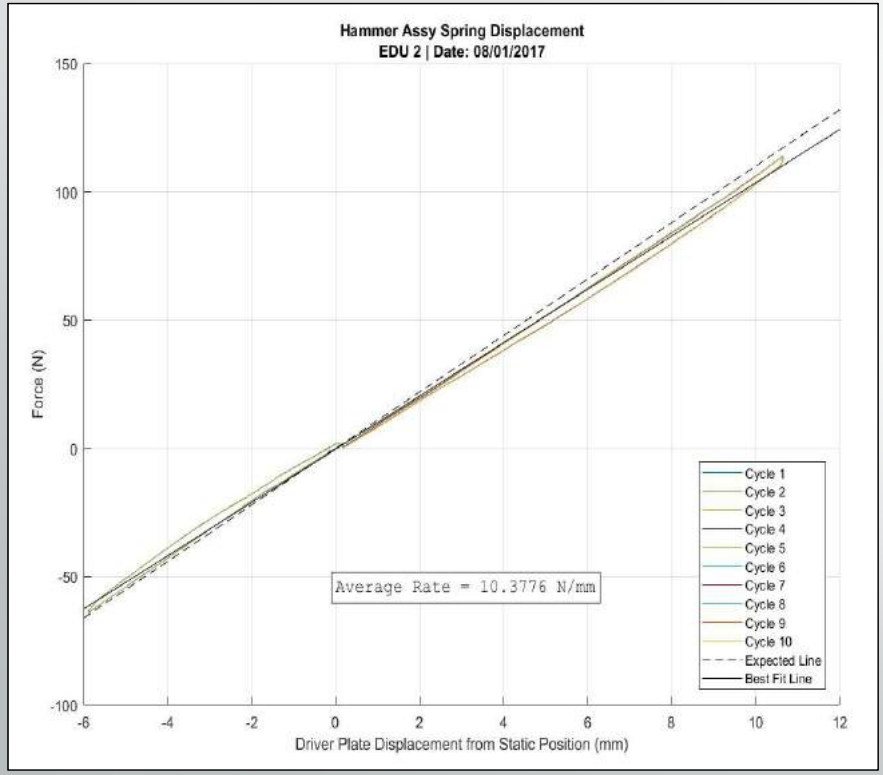
Measuring Height of Preloaded Springs



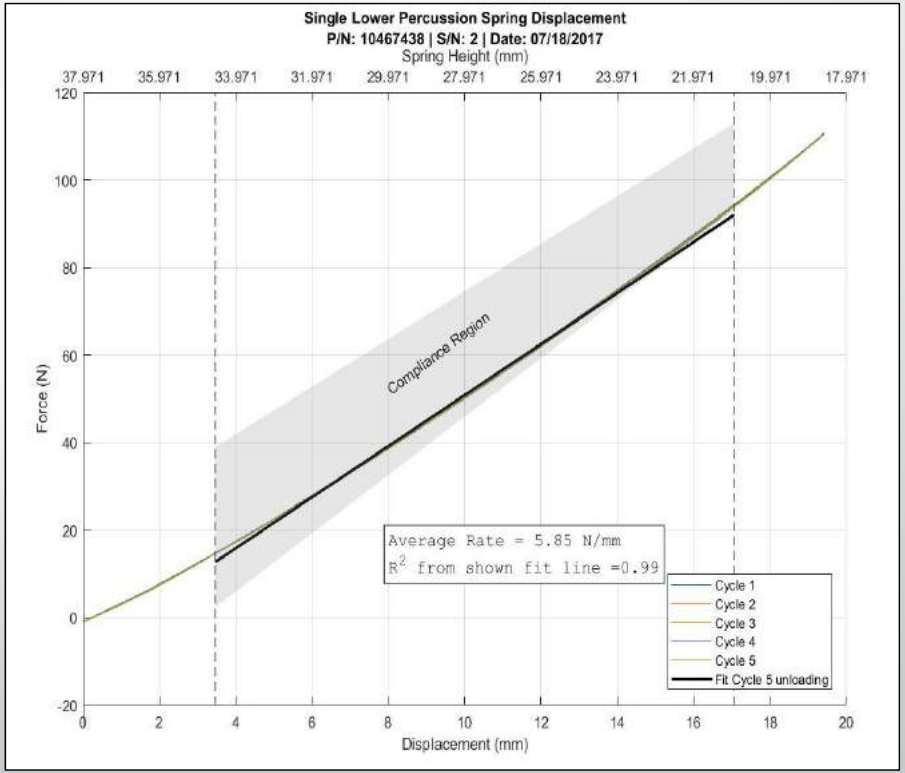
View of Assembly on IMADA

Data Analysis

Spring characterization was performed at regular interval throughout percussion unit life testing, which I was in charge of running. I imported data into MATLAB and wrote a script to generate these plots.



Displacement curve from hammer assembly (hysteresis observed)



Force-displacement curve for individual spring, with tolerance zone



Jet Propulsion Laboratory
California Institute of Technology

"Jeremiah essentially became the lead intern among three for many tasks – particularly related to testbed design and tasks related to tooling and assembly of the flight mechanism under test…

…Jeremiah is definitely self-motivated and is also very good at taking advantage of every opportunity to learn. He would always take the first step to move the project forward if I was not immediately available… "

- **Kyle Chrystal, Direct supervisor at NASA JPL, Percussion Unit Cognitive Engineer**

Full co-op evaluation and reference contact info available upon request.

Design and Manufacture of Tripod Bearing Housing – FSAE Electric Team

The tripod bearing housings transfer torque between the spool differential and the tripod bearing of the half-axles. Shown below is our 2017 FSAE Electric car's powertrain. I designed the majority of the system.



Turnbuckles for chain tensioning

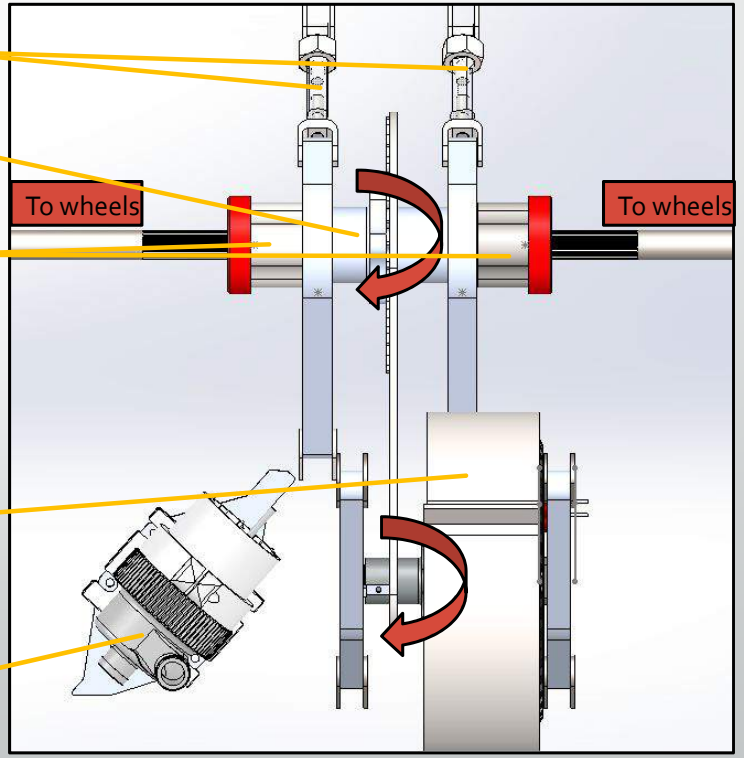
Spool Differential

Tripod bearing housings

Half-axles

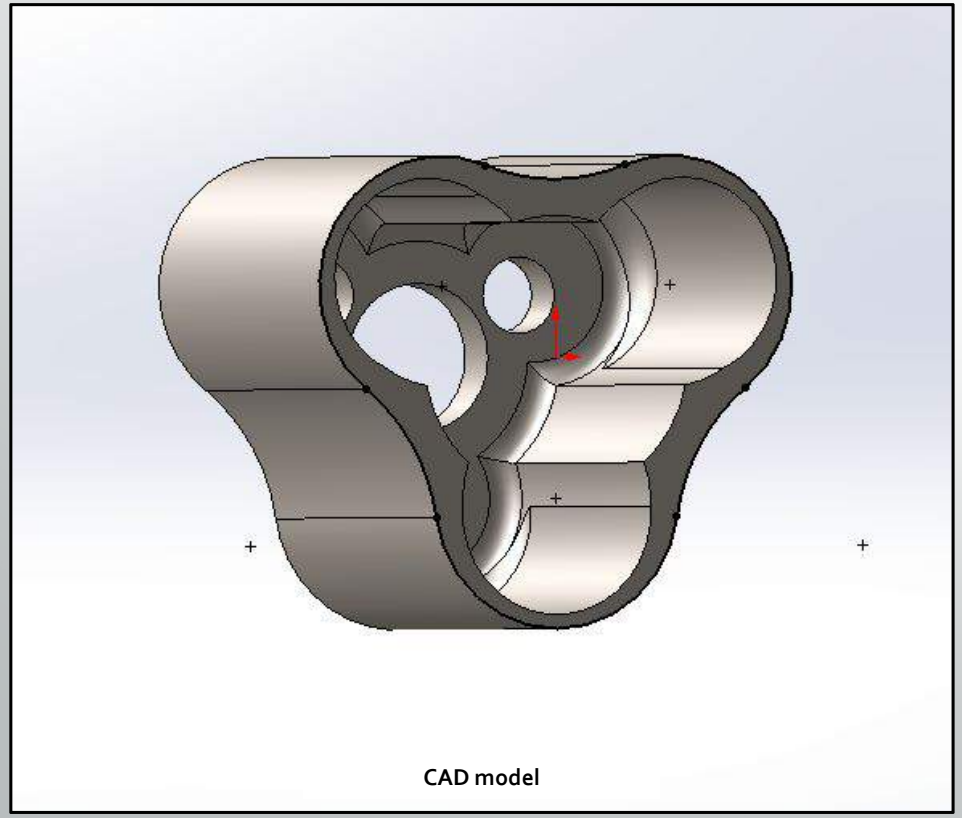
Emrax 228 Motor

Coolant pump



Tripod Bearing Housing

In addition to the CAD model, I 3D printed a test piece to ensure that it was actually possible to install lock wire for secondary retention.

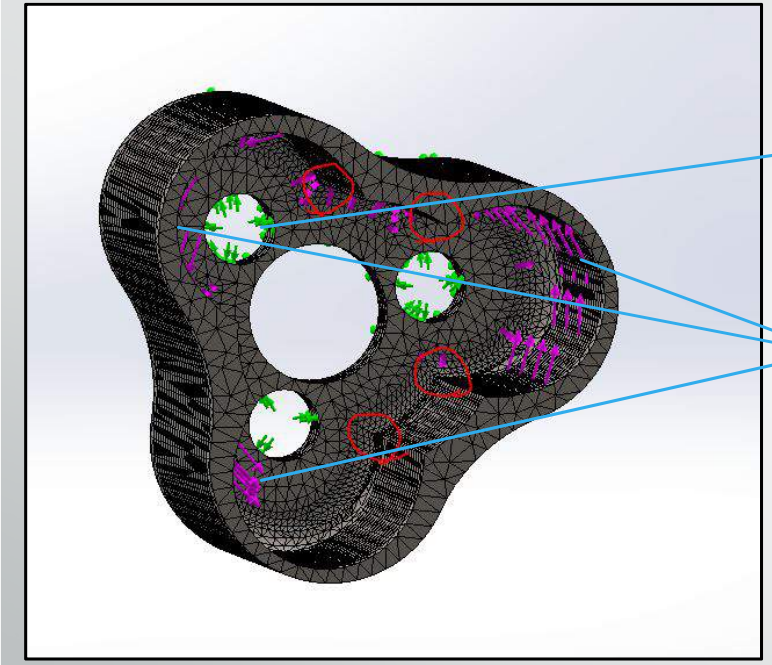


CAD model



3D-Printed Prototype

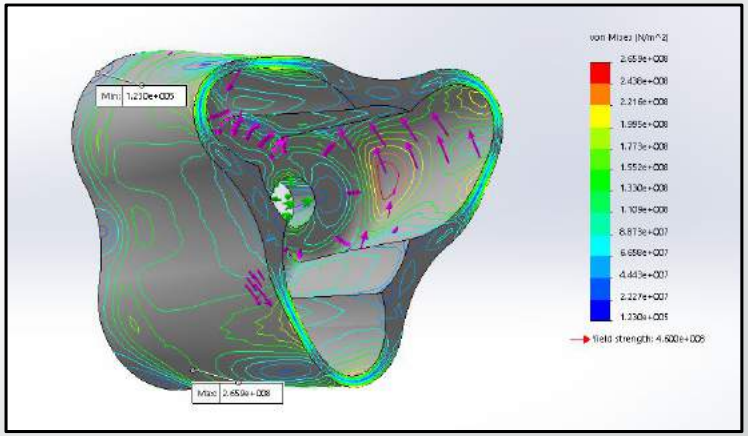
FEA



Constraints from bolted joint

Max motor torque from tripod bearings

Stress concentrations, circled (known from previous simulations)



FEA assumptions:

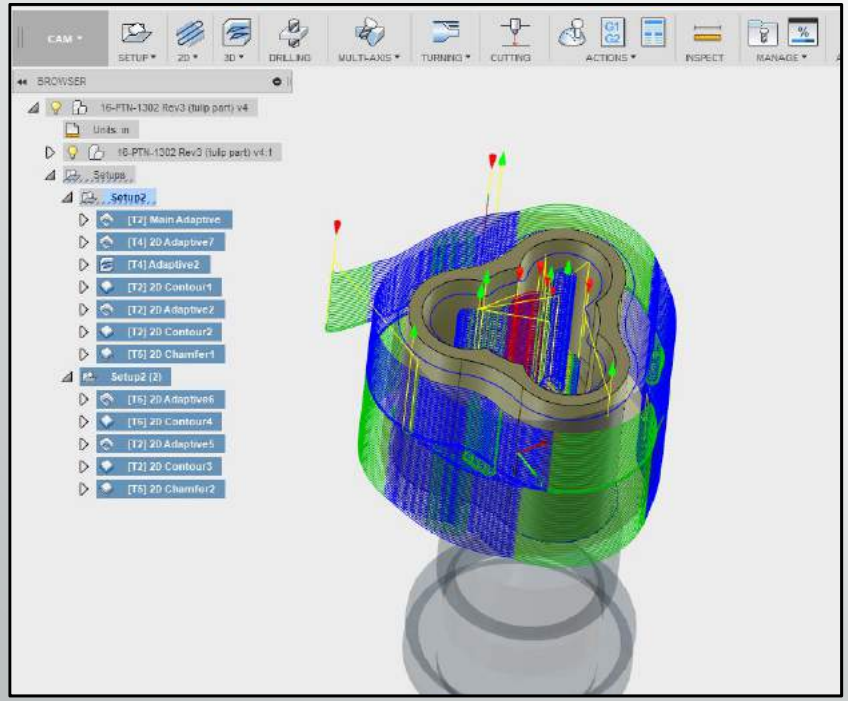
1) Hertzian contact points with bearings are not modeled (greatly reduces simulation time). Previous successful design had same geometric and material properties at contact points, and stresses should still be accurate at circled stress concentrations due to St. Venant's Principle.
2) Torque is equally distributed among three bearing lobes.
3) The tulip housing never slips against or loses contacts with spool differential.

Results give a safety factor of 1.73. Safety factor should be high enough to account for:

1) Variances in material properties, machining tolerances, and heat treatment processes.
2) Heat treatment will lower modulus of resilience, and part failure could lead to catastrophic consequence of inability to transfer torque to one wheel.

CNC Machining

I generated the G-Code with Autodesk Fusion 360 CAM, and machined both parts on a Haas TM-1 CNC mill.







Heat Treatment

4140 steel brought to austenitizing temperature, quenched, and then tempered to reach goal of 45 HRC (specified by manufacturer of tripod bearings).

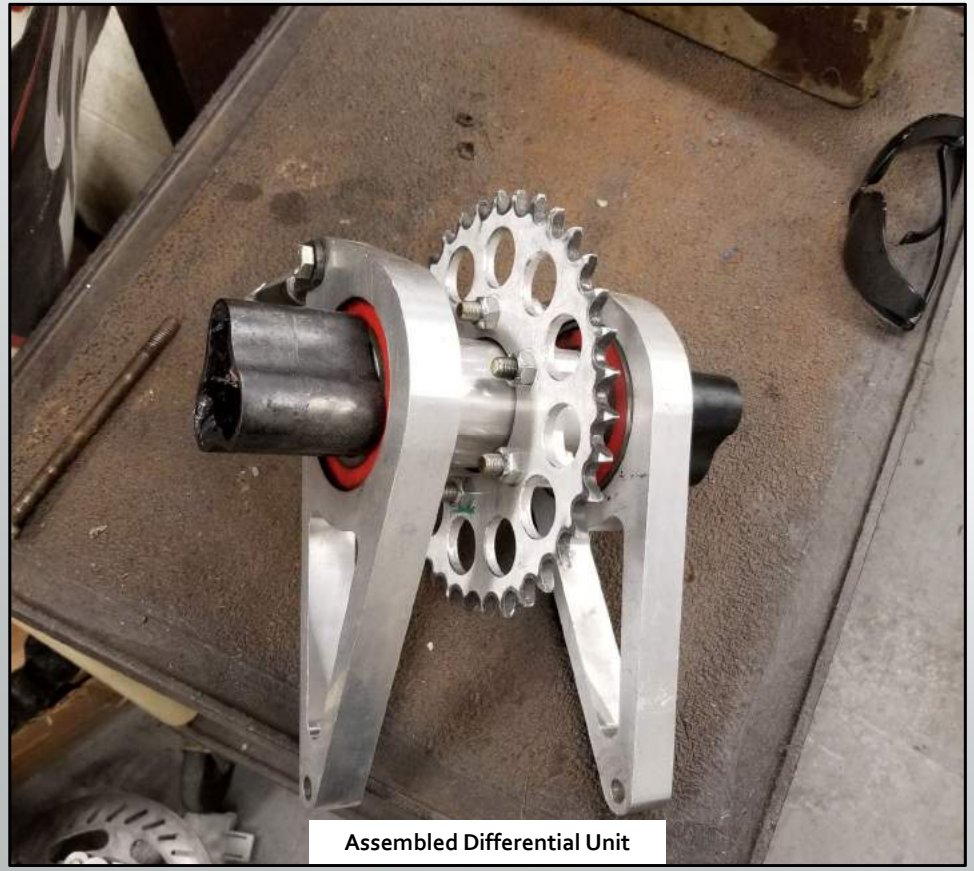


Post heat-treatment housings



Indentation test results

Final Assembly



Assembled Differential Unit



Formula Car Unveiling

Other Designed and CNC Machined Parts



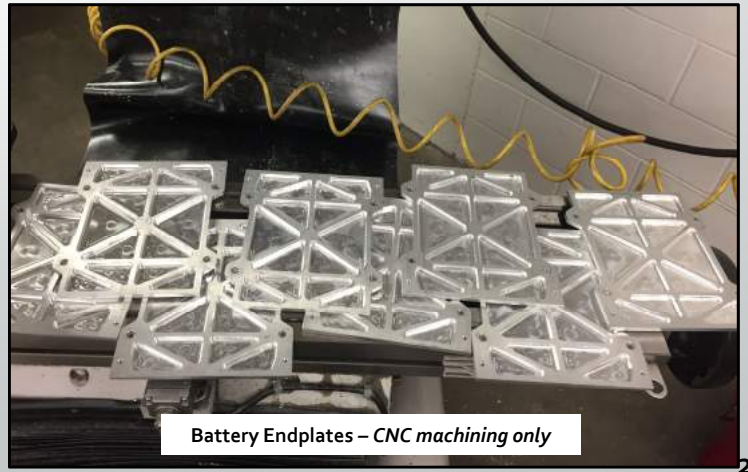
Spool Differential – *Design and CNC + manual machining*



Rear uprights – *CNC machining only*



Spool Pillow Blocks – *Design only*



Battery Endplates – *CNC machining only*

Thank You

Resume, references, and additional work examples available upon request.

- CAD models, FEA analysis, CAM, machined parts, videos
- NASA JPL Final Co-op Presentation, Summer and Fall Work Term Papers

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